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Recommendations for the Development of a Decision Aid for Probability Assessment in Prescribed Fires

Introduction

The Forest Service has asked Decision Research to review and critique two decision aids for making decisions about prescribed burns. Both aids were developed by David Bunnell. The first aid is a proposed approach to doing risk analyses of prescribed burning. The second is a matrix of risk assessment indicators for prescribed burns.

In this report we will first discuss the proposed risk analysis, then the proposed matrix of risk assessment indicators, and finally we will discuss whether the two aids can be combined.

The Risk Analysis

A prescribed fire is lit intentionally, to burn a prespecified area. However, ocassionally, despite all efforts, the fire escapes to burn outside the chosen area. The probability of such an escape and the damage from such an escape depend in part upon the characteristics of the site and in part upon the personnel and equipment available during the ignition and mop-up phases. David Bunnell has suggested that, during the planning of a prescribed fire, a small risk analysis be done as an aid in deciding how much personnel and equipment should be devoted to the fire. Each such risk analysis starts with the description of three alternatives, that is, three plans for personnel and equipment. Then three possible outcomes are

delineated, one with no escape, one with a minor, relatively controllable escape, and one with a major escape. These three possible outcomes are called "risk levels." For each of the nine combinations of alternatives and risk levels, the analyst must assess two numbers, the cost of that alternative-outcome combination and the probability of that outcome, given that alternative. From these assessments, the expected cost of each alternative can be calculated. The alternative with the lowest expected cost is considered to be the best alternative.

Strengths and weaknesses

The explicit quantification of costs and probabilities is both a strength and a weakness of this approach. It is a strength because such quantification encourages decision makers to think carefully about alternative courses of action. It emphasizes the idea that, although the chance of a major escape can be made small, it can never be entirely eliminated. Moreover, it makes clear that, in some cases, the cost of reducing the risk of escape may be greater than the benefits gained from the reduction.

Quantification is a weakness, however, if people believe that what is quantified is therefore precise. Such a belief will lead people to take such analyses more seriously than they deserve. Although both the cost estimates and the probability assessments will be grounded in past experience and, in some cases, based on firm data, in general the assessor will, of necessity, go beyond the known facts, using judgment and even intuition in arriving at the needed quantifications. To protect against the imputation of undue precision an analysis should always be accompanied by notes indicating the basis for the estimates and a list of factors that

were considered in arriving at the assessments. Such notes should also include ranges of values that the assessor believes are supportable. For example, a cost estimate of $361 per acre might be accompanied by a note indicating quite extensive data on this kind of fire, justifying a small range for the estimate of $350 to $370 per acre. On the other hand, the same estimate, when made for an unusual situation, might carry a note suggesting that the analyst's range is $200 to $500 per acre. Such notes would not change the analysis but would serve to remind others that estimates are not always precise.

The risk analysis Bunnell has proposed is relatively small in scope and size. Thus, it is quite incomplete. We believe that the simplification made by considering only three alternative courses of action and only three possible outcomes (that is, "risk levels"), rather than the multitudes of alternatives and outcomes that could, in theory, be specified, is not a substantial weakness of the method. Consider, in contrast, an analysis that included 15 possible courses of action and 12 possible outcomes. Such an analysis would require 180 cost estimates and 180 probability assessments! Busy decision makers might rightfully refuse to engage in such an analysis. Moreover, even if the more detailed analysis were done, it is doubtful that it would lead to a substantially better understanding of the situation and a better decision.

The choice of which three alternatives and which three outcomes should be used in the analysis is, of course, a critical one. The set of chosen alternatives should span the range of feasible alternatives; the set of outcomes should span the range of what could really happen as a result of the fire. There are no tricks or methods for making these choices; common sense must be used. In some cases, an expansion to four or five

limited expansion of alternative set

alternatives or outcomes may help the analyst organize his or her knowledge without unduly complicating the analysis.

The primary weaknesses of the proposed risk analysis are the omission of all adverse consequences except the risk of escape from the prescribed fire boundary and the omission of less tangible costs. In some of his examples, Bunnell notes some considerations which he did not include in the analyses, such as the possibility of not meeting prescribed burning objectives, the element of personnel safety, and adverse public reaction:

> . . . the unit was within 5 miles of the local municipal airport at Missoula, Montana; residual smoke from prolonged mop up could have been a daily flight hazard; the Missoula airshed is prone to temperature inversions and is extremely politically sensitive to smoke pollution; residents would be adverse to long smoke duration from this source; and the Agency may have received criticism for unprofessional ethics due to the visibility for this project.

include the non-econ effects

In Bunnell's examples, the considerations not included in the analysis favored the same alternative as did the analysis and thus reinforced the decision. This will not generally be the case.

We are sympathetic to Bunnell's decision to exclude many factors from the analysis. These factors are hard to quantify; for example, no one knows the cost, in dollars per acre, of antagonizing the Missoula residents and bringing criticism down on the Agency. The full panoply of the techniques of decision analysis could be used to model all the factors relevant to a prescribed-burn decision. However, we believe that a major research effort of several years duration would be required to develop such a model into a practical set of templates and guidelines, such that it could be used routinely by land managers.

Recommendations for use

In view of the incompleteness of the analysis, we recommend that it not be used to make prescribed-burn decisions, in the sense that land managers would be expected to follow the dictates of the analysis. However, we believe that such analyses could be very useful to the Forest Service:

1. As decision aids for the land managers. The very act of performing the analysis will help the decision maker to think clearly about the problem. Choosing which three outcomes to include in the analysis, choosing three action alternatives, estimating the costs, assessing the probabilities; all the steps of the analysis require thought about the problem at hand. The analysis then displays the results, the logical implications of the analyst's beliefs, in an organized way. The decision maker can then focus separately on the factors that are not included in the analysis. This separation of tasks should greatly aid the decision maker.

2. As a protection against "Monday morning quarterbacking." In an uncertain world, the improbable sometimes happens. When unlikely but really bad outcomes ensue, we are all tempted to say "You should have known." When so attacked, the land manager can pull out the previously-performed risk analysis (even if it is just sketched out on the back of an envelope) to show that the actual outcome (or one much like it) had been considered, but that, at the time, other considerations outbalanced that one.

3. As data for future analyses. Over time, the Forest Service will find that a collection of these brief risk analyses, along with records of the actual outcomes, will provide invaluable evidence for improving both knowledge about escapes and decisions about prescribed burns.

4. As a training tool. A risk analysis can be used as a form of communication: "This is why I took this action."

Recommendations for improvement

Sensitivity analysis. As previously noted, we recommend that each risk analysis be annotated with comments on the sources for the estimates and the reasonable range for each estimate. These ranges can be used in a sensitivity analysis; we recommend that analysts be encouraged to perform sensitivity analyses. A sensitivity analysis is simply a series of "what if" questions. Each estimate or probability assessment is given a new value, usually the largest or smallest value that the analyst thinks is reasonable. The risk analysis is then recalculated to see if the decision is changed, that is, if a different alternative now has the lowest expected value. If the order remains the same, the risk analysis is considered to be insensitive to that estimate. Doing a sensitivity analysis can indicate the degree to which a risk analysis can be relied upon. The analyst need not change every estimate and assessment, but do so only for the most uncertain estimates and the assessments for which the analyst feels most vagueness. It is customary to change just one cost or set of probabilities at a time. However, when time permits, it is also appropriate to change several numbers at a time (e.g., what if I have underestimated both the cost of an escape and the probability of an escape for the currently favored alternative?).

interaction sensitivity

An alternative way of doing sensitivity analysis, which may give more information but which requires a bit of algebra, is to ask, for a specified cost or probability, how large or small this number must be before some

other alternative is favored. This approach will be illustrated using Bunnell's Example 2:

Risk	Alternate 1		Alternate 2		Alternate 3		Weighted Project Cost		
Level	$	Prob.	$	Prob.	$	Prob.	1	2	3
1	6,480	.975	3,700	.90	2,500	.80	$6,318	$3,330	$2,000
2	8,480	.02	5,700	.095	4,400	.19	170	542	836
3	53,480	.005	50,700	.005	49,400	.01	267	254	494
Total Weighted Project Cost (i.e., Expected Value):							$6,755	$4,126	$3,330

In this example, Alternative 3 (with the lowest level of personnel and equipment) has the lowest expected cost. One reason for this is that the probability of a major escape (Risk level 3) is larger than for the other alternatives, but not by much. How likely would a major escape have to be under Alternative 3 to make Alternative 2 become favored? In order to change one probability, we have to change more than one, because the sum of the three probabilities within an alternative has to be 1.0. Let us assume, for our algebra, that within Alternative 3, the probability for Risk Level 1 is four times as large as the probability for Risk Level 2 (as it is, approximately, now). Let x be the probability of Risk Level 3 for Alt. 3. Then the probability of Risk Levels 1 and 2 combined is (1-x), which we will assign four-fifths of to Level 1 and one-fifth of to Level 2. Now we want to know the size of x that will make Alternative 3 look as bad as Alternative 2 (the next-best alternative).

paired comparison generation of sensitivity

$$2500(4/5)(1-x) + 4400(1/5)(1-x) + 49400(x) = 4126$$

Solving for x, we find that x = .027. Thus, changing only the probabilities associated with Alternative 3, and keeping the approximately

4 to 1 ratio between the first two, we would have to increase the probability of a major escape to greater than .027 in order for the risk analysis to favor Alternative 2. For example, a change from the original probabilities, (.80, .19, .01), to the probabilities, (.79, .18, .03), would yield an expected project cost for Alternative 3 of $4249, slightly above the $4126 cost of Alternative 2. Now the analyst knows what to concentrate on. Is it reasonable to suppose that the probability of a major escape is as large as .03 for this site under Alternative 3? If so, perhaps there is a way to change Alternative 3 to bring this probability down. Or maybe Alternative 2 really is best.

risk mgt. focus

Using the same example, let us now do a sensitivity analysis on the cost of a major escape. If this cost was badly estimated for one alternative, it was probably badly estimated for all alternatives. Let us suppose that whatever the new cost is for Alternative 3 (call that y), it will still be $1300 smaller than the cost for Alternative 2. Keeping the same probabilities and the same costs for Risk Levels 1 and 2 as in the original, we will recalculate the expected cost of both Alternative 2 and Alternative 3 and set them equal to each other. So our equation this time is:

$$.005(y + 1300) + 542 + 3330 = .01(y) + 836 + 2000$$

$$y = 208,500$$

This time our sensitivity analysis has led us to a comforting conclusion. It says that with all else equal, the cost of a major escape would have to increase from around $50,000 to over $200,000 before Alternative 2 would be favored. We presume that the expert who provided the original estimates would not hesitate to say that this new cost is not a reasonable estimate.

In short, sensitivity analyses can tell the analyst where accuracy is critical to the conclusions of the risk analysis and where accuracy is not so important.

Enlarging the model. We recommend that the present model (with the additions of annotations and sensitivity analysis) be used now, but that the Forest Service also begin the effort of expanding the model to include all relevant costs and considerations. This could be done using decision analysis. An explication of the methodology of decision analysis is beyond the scope of the present report.

Assessing probabilities. Assessing the probabilities needed for a risk analysis is never an easy task. Small probabilities are especially difficiult to think about. The following suggestions might be useful.

First, how might one think about probabilities? It is common to think of probabilities in terms of relative frequencies: Of all the burns like this one, what percentage of them escaped? We do not recommend an emphasis on the frequentistic approach, because of the difficulties of defining the class of "burns like this one." Each prescribed fire is unique; one cannot be sure of what dimensions of similarity should be used in forming a class.

difficulties in drawing similarities

Instead, we suggest that analysts think of probabilities as expressions about fair bets. Consider the kind of bet for which one puts up a stake of $1, losing the stake if the event does not occur and receiving a return of $R (including the stake) if the event does occur. Then the probability of the event, in order for the bet to be fair, is p = 1/R. Thus, to say that the probability of escape is .01 means that the analyst regards as fair a bet that, with a stake of $1, would return $100 if an escape occured. This does not mean that the analyst would be willing to enter such a bet, only that the analyst considers the bet to be fair.

Another way of thinking about probabilities is that they are numerical expressions of one's degree of belief, with 0.0 meaning "I believe this event to be utterly impossible" and 1.0 meaning "I believe this event to be absolutely certain."

When one thinks about probabilities as fair bets or as numerical expressions of one's degree of belief it is still appropriate to take into account whatever frequentistic information one has. But one is not limited to relative frequencies; one can, and should, make use of all the information one has, whether or not the information is in frequentistic form.

One good way of eliciting probabilities is by using reference gambles. Imagine a circle with a spinner in the center. A sector of the circle, shaped like the slice from a pie, is colored red. This device can be used to decide a gamble: Spin the spinner. If it stops in the red sector, the gamble is won. Now consider a choice between two gambles. The first gamble is the reference gamble. You win $100 if the spinner stops on the red. The second gamble concerns the event you are trying to assess. You win $100 if the fire does not escape. Vary, in your mind, the size of the red sector, and each time, ask yourself which gamble you would prefer to play. If the red sector is small, you would prefer your possible $100 prize to be determined by the second gamble; if the circle were completely red, you'd prefer the reference gamble. Find the size of the red sector such that you are completely indifferent between the two gambles. The proportion of red to the whole circle is then the probability you are seeking. You may find that there is a range of sector sizes such that you are indifferent between the two bets for all the proportions in the range. Then this is the range of probabilities that can be used in a sensitivity

ranges of probabilities

analysis. Attached to this report are a few pages from a text illustrating this method.

The reference gamble method is suitable for assessing pairs of probabilities, the probability that an event will occur and the probability that it won't. Bunnell's proposed risk analysis requires probabilities for three or more events. We suggest that the assessor pick one event and assess it (and its complement). Then assess the remaining pair, conditional on the falsity of the first. For example, first assess the probability of no escape. Then assess the relative likelihood of a minor vs. major escape, assuming that there is an escape. Finally, apportion the remaining probability in the same ratio as the conditional assessments. Thus, if the probability of no escape is .8, the remaining probability is .2. Suppose the probability of a minor escape, assuming that there is an escape, is .9 and the probability of a major escape is .1. Then .9 times .2 = .18 is the unconditional probability of a minor escape and .1 times .2 = .02 is the unconditional probability of a major escape.

An alternative approach to assessment is to assess only ratios. For example, you might believe that Event 2 is 3 times as likely as Event 1 and that Event 3 is 12 times as likely as Event 2 (which implies it is 36 times as likely as Event 1). If the three events are the only possible events, these two judgments completely specify the desired probabilities:

$$P(E_1) + P(E_2) + P(E_3) = 1$$

$$P(E_1) + 3P(E_1) + 36P(E_1) = 1$$

$$40P(E_1) = 1$$

$$P(E_1) = .025$$

$$P(E_2) = .075$$

$$P(E_3) = .9$$

double checking with RATIO ASSESSMENT

If the probabilities are assessed directly, they should be reexamined as ratios (does it seem right that this event is xx times as likely as that event?); if ratios are used as the basis for the assessment, the resultant probabilities should themselves be examined for reasonableness. In other words, it's a good idea to make probability assessments two ways to verify that they seem reasonable from two points of view.

Very small probabilities are especially hard to assess. Usually our knowledge and intuitions are weak when it comes to saying whether the probability of an event is, say, .005 or .001. One way of approaching small probabilities is by way of conditioning events. It's like building a little scenario of how the focal event could happen. It's important, however, to consider <u>all</u> the ways the event could happen. This approach requires some knowledge of the rules of probabilities. The following rules may help the beginner:

"Or" means add.

"And" means multiply.

However, two or more probabilities can be directly multiplied only if all the events involved are independent. If not, one must use conditional probabilities. A test for independence is the answer "no" to the questions "If event A occurs, does that change my belief in the probability of event B occuring?" and "If event B occurs, does that change my belief in the probability of event A occuring?" For example, if it's raining, the probability that the temperature is below 70 degrees is higher than if it's not raining. The event "rain" is <u>not</u> independent of the event "temperature below 70 degrees."

Suppose you believe that a major escape (event "E") can happen under Alternative 1 only if the temperature rises (event "TR") <u>and</u> the helicopter

crashes (event "HC"). Suppose further that you believe TR and HC are independent (knowing that a helicopter crashed doesn't change your belief in the possibility of a temperature rise, and knowing that the temperature is rising doesn't change your opinion about the possibility of a helicopter crash). Then

$$P(E) = P(TR) \text{ times } P(HC) \quad .$$

The point to developing this little scenario and equation is that the component probabilities may be easier to assess than the target probability. Here, if you can assess the components, you need only multiply them to get the probability you need.

Now consider a scenario with dependent events: You believe that a major escape can happen only if the temperature rises and the wind changes ("WC"). But you also believe that a wind change is more likely if the temperature rises. So you can't just multiply the two together. Instead, you have to condition one on the other. You'll have to choose which of these two pairs of events is easier to assess:

Pair 1: Assess P(TR), the probability of a rise in temperature
and P(WC/TR), the probability of a wind change, assuming that the temperature rises.

Pair 2: Assess P(WC), the unconditional probability of a wind change
and P(TR/WC), the probability of a temperature rise, assuming that the wind changes.

Either pair will do the job, because:

$$P(E) = P(TR) \text{ times } P(WC/TR) = P(WC) \text{ times } P(TR/WC) \quad .$$

For three or more dependent events, all of which have to occur for the target event to occur, the conditioning builds in this fashion:

$$P(E) = P(A) \text{ times } P(B/A) \text{ times } P(C/A,B) \text{ times } P(D/A,B,C) \quad .$$

P(C/A,B) means the probability of event C assuming that both A and B occur and P(D/A,B,C) means the probability of event D assuming that all three of the events, A, B, and C, occur.

If there are two or more pathways to the target event, the components of each pathway are added. For example, if an escape can occur either because the wind changes and the temperature rises or because the temperature rises and the helicopter crashes, then

$$P(E) = [P(TR) \text{ times } P(WC/TR] + [P(TR) \text{ times } P(HC)] \quad .$$

These equations can look very complex; one might therefore wonder if they really help in probability assessment. We believe they often will, because an expert's knowledge is often organized around sequences of events. Acknowledging these sequences in equations like the above allows the expert to assess probabilities in a way that corresponds to the expert's knowledge. They may be especially suited for disasterous events like a major escape. Because such escapes are costly, many efforts are taken to avoid them. They can thus occur only if several things go wrong at once. The probability of an escape is thus very small, perhaps too small to assess comfortably. But the probabilities of each of the component things that all need to go wrong at once in order for an escape to occur may be quite a bit larger, large enough to assess more easily. For example, using the equation:

$$P(E) = P(A) \text{ times } P(B/A) \text{ times } P(C/A,B) \text{ times } P(D/A,B,C) \quad ,$$

if each of the four components is equal to .2 (a moderate probability), then P(E) = .0016. If each component probability is .05 (small, but not too small to conceptualize), then P(E) = .00000625, a very small number, indeed.

need recommendation here

risk levels defined on prob. and consequence

The Risk Assessment Indicators Matrix

The second decision aid designed by David Bunnell is the Risk Assessment Indicators Matrix. This matrix contains 20 characteristics of a prescribed-burn situation that relate to the probability of an escape. The 20 indicators are organized into three groups: site characteristics, containment factors, and prescription parameters. Each indicator scale is divided into five or six levels (e.g., % Slope: < 15, 15-30, 31-45, 46-60, and > 60); associated with each level is a score from 0 to 5 that roughly indicates the risk of that level. When a prescribed-burn situation is evaluated using the matrix, the scores are summed across the 20 indicators to yield a total score. The higher that score, the greater the risk of escape.

Recommendations for use

The matrix does not yield a probability, only a score on an arbitrary scale. It seems unlikely that a reasonable translation from score to probability could be made. One way of doing that would be to collect data about prescribed burns, noting the total score and its components and whether or not there was an escape. But we suspect that the translation would not be clear until perhaps 50,000 burns were observed. One would not expect prescribed-burn technology to remain constant over such a long period of time. Another way of making the translation would be to ask experts to make judgments about the correspondence between total scores and probabilities. However, since any particular total score could result from an enormous variety of different matrix profiles, we fear that experts would have great difficulty relating the scores to their knowledge.

score → prob. difficult

Thus the matrix should not be looked upon as a mechanical way of assessing the probability of an escape. However, we believe that the matrix could be highly useful in a number of ways:

1. Focussing. The matrix could be used as an informal aid, to describe and focus attention on a particular site, when prescribed-burn decisions are being made and when the probabilities needed for the previously-discussed risk analysis are being assessed.

Note, however, that the analyst must consider more information than is represented in the matrix when making probability assessments for a risk analysis. First, the risk analysis requires a distinction between minor escapes and major escapes. That distinction is not made in the matrix. Second, the probabilities in the risk analysis are conditional upon a given level of personnel and equipment.

Link from matrix to prob. for different levels of escape

Despite these differences, the matrix could be quite helpful. Breaking a compex task (like probability assessment) into smaller tasks (first, let's consider the site; later, the personnel and equipment) can reduce the information-processing load on the assessor and thus may lead to more consistent, reliable, and reasonable assessments.

2. Timber sales. This matrix could be quite useful in the design of future timber sales. It will suggest ways in which the design could be changed to lower the risk of escape when the site is burned at a future date. For example, the shape of the site might be altered.

3. Communication and training. The matrix is an excellent communication device. It could be used as a clarifying aid in communications between line and field officers and as a way of transmitting the knowledge of experts to Forest Service trainees.

4. "What if?" The orderly display of information in the matrix might encourage the exploration of alternative courses of action. It has this potential in the design of timber sales and the planning of perscribed burns. But in addition, if the matrix were regularly used, the resulting profiles and results (did the fire escape?) could provide the basis for suggesting topics of special concern and evaluating the priorities for future research to reduce the risk of prescribed burns. Since for this purpose the arbitrary scales in the matrix need not be converted into probabilites (since setting priorities requires only a rank-ordering of risky situations), we would expect that the data set would be a rich source of insight not after 50,000 burns but after a season of burns.

Recommendations for improvement

Independence. The score resulting from use of the matrix will have more meaning if the indicators chosen for inclusion in it are independent of one another. Here we refer to the intercorrelations among the indicators across different burn sites. It may be, for example, that the indicator "10 Hour Fuel Moisture Content" is highly correlated with "1,000 Hour Fuel Moisture Content," in that a low value on one and a high value on the other would be very unlikely to occur in the same site. The problem with unexamined interdependencies is that their existence makes it almost impossible to make sensible judgments about the relative importance of each indicator in determining risk. We recommend that the list of indicators be examined for possible interdependencies and that the list be revised to eliminate such interdependencies.

reformulate the matrix

Searching for dependencies means making expert judgments about each pair (or even triple) of scales. For any pair of scales, one asks, "If you

knew that Scale A was at its highest (most risky) level, would that knowledge give you any information about the level of Scale B?" This is a paraphrase of the test for independence discussed earlier. Alternatively, one could ask for direct judgments of correlation: "Are Scales A and B correlated?" Another approach would be to ask, "Are there any profiles (specific combinations of levels of the indicators) that would surprise you or that are improbable or even impossible?" It is better to use several approaches, not just one.

Once the dependencies are identified, they should be eliminated. This can be done in one of three ways:

1. Delete one or more scales. This is appropriate when the correlation between two scales is very high, even if the apparent content of the scales differs.

2. Combine two scales into one, retaining the names and level descriptors of both. When the user is occasionally faced with a site for which the two levels differ (this will be rare if the correlation is high), the user can select an intermediate level.

3. Combine two or more scales into one new scale, perhaps one with a new label and scale indicators. It does not matter that the content is the same as the original scales, only that the new scale is related to the risk of escape in the same way as the old scales. (For example, over the centuries there has been a very high correlation between the human birth rate in The Netherlands and the observed nesting activities of storks, a correlation presumably mediated by the availability of food. Thus in some imagined model of Dutch economic conditions one could replace the human birth rate scale and the stork nesting scale by a single scale measuring, say, the size of the potato crop).

Range. In Bunnell's matrix the levels of every indicator range from a score of 0 to a score of 5. This implies that going from lowest to highest on any one scale has exactly the same impact on the risk of escape as going from lowest to highest on any other scale. This equal weighting seems unlikely to us. We recommend that its validity be examined by asking experts questions like, "What would have the greatest impact on risk, going from best to worst on Scale A or going from best to worst on Scale B?" for every pair of scales. The results of such a series of judgments would provide a rank order of importance for the indicators. Note that such questions would be difficult to answer or even meaningless for pairs of highly correlated scales. Thus the previously-described task of developing independent indicators should be performed first.

equal weighting assumption

If, as we suspect, not all the scales are of equal importance, this fact should be reflected in the assignment of scores to scales. Starting with the indicators rank-ordered by importance, one needs to develop a measure of importance for each. Ratio judgments are usually used for this task. Start with the least important indicator and assign it a (temporary) importance weight of 10. Then consider each other indicator and assign it a number such that the ratio of numbers reflects the ratio of importance. For example, if Scale B is 20% more important than the least important scale, assign it the number 12; if it is twice as important, assign it the number 20. The order in which the scales are considered does not matter much. Make whatever comparisons seem most meaningful. The task may seem quite difficult. However, great accuracy is not needed; small differences in importance wights have very little effect on the total score.

scoring the SCALES RANK, then RATE (weight)

These importance weights can be used to assign scale values to the levels of each scale. The least important scale and all other scales of

approximately the same importance can retain their scale values ranging from 0 to 5. More important scales should have larger ranges (always anchored at 0, for convenience); the range should proportionately reflect the importance. A scale twice as important would have a range from 0 to 10. Each level of each indicator then is assigned its scale value within that range. The scale values can be equally spaced. However, an expert may feel strongly for some indicator that risk does not increase linearly as the level increases (e.g., "The risk due to slope really isn't much until the slope is worse than 40%; then the risk increases rapidly.") In such cases the scale values assigned to the levels can be adjusted accordingly. Here again, great accuracy is not needed; rough approximations will suffice.

There will no longer be a tidy constancy of scale value across the rows of the matrix; the scale value will have to be written inside each cell of the matrix. This shouldn't make the matrix appreciably more difficult to use in the field.

Non-compensatory indicators. Finally, some thought should be devoted to the possibility that there are some conditions that indicate high risk of escape even when all other indicators are very low. The present matrix reflects an underlying assumption that the presence of a high level of any one indicator can be compensated for by a low level of some other indicator. This is probably generally true, and represents an improvement over the earlier "window" approach, under which every indicator had to be within some prespecified boundary for a burn to be approved. However, it might be worth exploring the possibility that one (or more) indicator is non-compensatory--if it reaches some dangerous level, the risk is high regardless of the other indicators. There is no especially preferred way

of eliciting such information from experts. Nor is there any easy way to change the matrix if such non-compensatory levels are found. Simply giving that cell an extra-high scale value is not a theoretically justified solution but might work in practise.

Another possibility is that two or more indicators, when both have high levels, represent a risk that is greater than the sum of their two scale values. This might be elicited from an expert by asking, "Is there any especially dangerous combination of factors?" If such a combination is found and is believed to be significant, one solution would be to combine the two scales into one, but this might be cumbersome. Instead, the matrix could just include a footnote saying: "Add zz points if Scale A is at level xx and Scale B is at level yy."

add points for non-compensatory combinations

There is a danger that including too many knobs and whistles will make the matrix unappealing to the potential users. Therefore, corrections for non-compensatory factors should be made only if the experts judge them to have quite powerful effects on risk.

Overview

We believe that the two decision aids here reviewed show great promise for practical application. One of their greatest virtues is simplicity. We have tried to make suggestions for improvements that, if implemented, would increase the aids' usefulness without making them too cumbersome.

At the same time, the Forest Service might profit from a longer-range project in which completeness, rather than simplicity, is the goal. If a far more complete model is developed, steps can then be taken to make it practicable, by introducing rules of thumb, templates, or computer subroutines for its separate parts.

The two decision aids here considered are not now in such form that they can be directly combined. Taken together, however, they suggest that the probability of escape might be approached by first separating the factors into aspects beyond the control of the line officer (e.g., most of the site characteristics) and aspects affected by the line officer's fire plan and execution (e.g., personnel). This division may ease the modeling task.

decompose the matrix

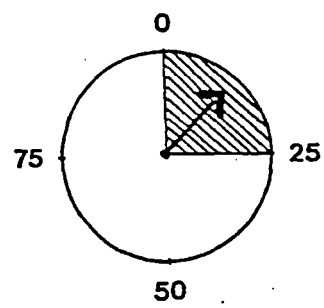
Appendix

Excerpt from:

Beyth-Marom, R., Dekel, Shlomith, Gombo, R., & Shaked, M. (1985). An Elementary Approach to Thinking Under Uncertainty. Hillsdale, NJ: Lawrence Erlbaum. Pp. 47-50.

4.6 ELICITING NUMBERS TO EXPRESS DEGREES OF BELIEF

We may overcome the difficulty in eliciting numbers with the help of a small device called a *chance wheel.* This circular device represents our total store of confidence. Around the circle there are numbers from 0 to 100. The device is actually composed of two interlinked circles, one dark and one light. The user can manipulate the device to change the size of the dark sector from 0% to 100% dark. The numbers around the circle indicate what percentage of the circle is dark. In the middle of the circle there is a pointer that we can spin. If we spin the pointer, the chances that it will land in the dark sector are the same as the proportion of the circle that is dark. When we say we assign "25" to the chances that it will rain tomorrow, we mean that 25% of our store of confidence is assigned to the outcome "rain" and the remaining 75% is assigned to the outcome "no rain." These assignments are the same as the chances that the pointer, when spun, will stop in the dark sector (25% chance) or the light sector (75% chance).



To illustrate the use of a chance wheel, suppose Ellen wishes to elicit from Arthur his degree of belief in the proposition, "In the next election the present mayor of our town will be reelected."

Ellen: What do you think are the chances that in the next election the present mayor will be reelected?

Aruthur: I have no idea.

Ellen: I am sure you have some beliefs about it.

Arthur: Yes, I think that the chances are small.

Ellen: How small?

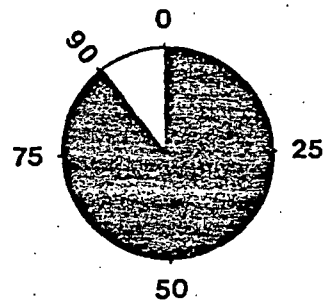
Arthur: I don't know.

Ellen: Okay, let's find out. I'll offer you two gambles. One gamble involves the mayor. The other involves the chance wheel. In either gamble you can either win $100 or lose nothing. All you have to do is tell me which gamble you'd rather play.

Step One

Gamble Number 1. After the election, we will see who the mayor is. If it's the present mayor, you win $100. If it's someone else, you will neither win nor lose anything.

Gamble Number 2. After the election, we will spin the pointer on this chance wheel, with the wheel set at 90% dark. If the pointer stops in the dark area, you will win $100; if the pointer stops in the light area, you neither win nor lose anything.



Which do you prefer, the first gamble, or the second gamble?

Arthur: I prefer Gamble 2; I'm nearly sure I will win.

Ellen: What do you mean by "nearly sure"?

Arthur: There's 90 chances out of 100 to win.

Ellen: Can I infer from this that the mayor's chances of reelection are smaller than 90?

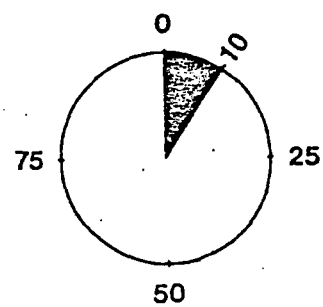
Arthur: Sure.

Ellen: Okay, here's another choice between two gambles.

Step Two

Gamble Number 1. After the election, we will see who the mayor is. If it's the present mayor, you win $100. If it's someone else, you will neither win nor lose anything.

Gamble Number 2. After the election, we will spin the pointer on the chance wheel, this time with the wheel set 10% dark. Now which of these two gambles do you prefer?



Arthur: On the wheel, there's not much chance of winning. I'd have a better chance to win with the mayor; I'll go with Gamble 1.

Ellen: May I infer that the mayor's chances of reelection are larger than 10?

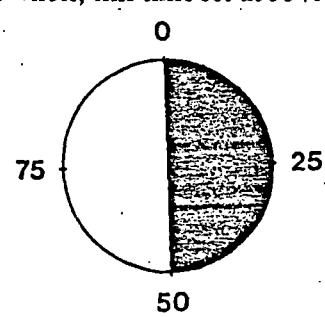
Arthur: Right.

Ellen: Okay, let's try again.

Step Three

Gamble Number 1. Gamble 1 is on the mayor again. It's the same gamble as in the first two steps.

Gamble Number 2. Again we use the chance wheel, this time set at 50% dark. Which one of these two gambles do you prefer now?



Arthur: I prefer Gamble 2.

Ellen: May I infer that the mayor's chances of reelection are larger than 10 but smaller than 50?

Arthur: Sure.

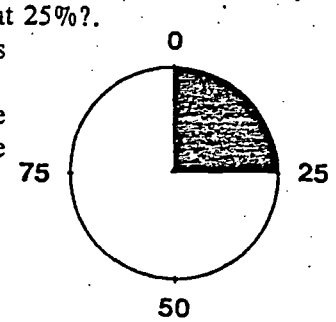
Step Four

Ellen: Now which do you prefer: Gamble 1 to receive $100 if the mayor wins, or Gamble 2 with the chance wheel set at 25%?.

Arthur: That's a hard one. It's close. I guess I'll go for the mayor, Gamble 1.

Ellen: So now I'm inferring that you believe the chances for the mayor's reelection are more than 25 but less than 50.

Arthur: Yes, that's right.



Step Five

Gamble Number 1. After the election, we will see who the mayor is. If it's the present mayor, you will get $100. If not, you won't win anything and you won't lose anything.

Gamble Number 2. The chance wheel again, set this time at 30% dark.

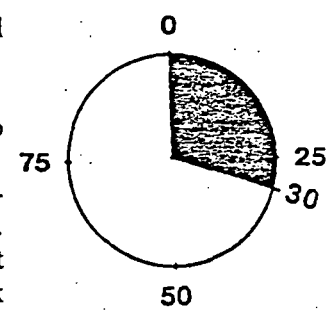
Arthur: I have a hard time deciding.

Ellen: Do you have any preference at all? Do you care which gamble you play?

Arthur: I don't know. I just can't choose between them. I really don't care which one I get.

Ellen: So is it reasonable for me to say that the chances that the pointer will stop in the dark area of the circle are the same as the chances you give to the mayor's reelection, 30%?

Arthur: Yes.



Those five steps enable us to elicit a number that expresses Arthur's degree of belief. Arthur felt as if he couldn't express his feelings with a number, but he found he could choose between two gambles. In the end, his choices conveyed to Ellen his degree of belief. This happened at the *indifference point,* when he was indifferent between the two gambles. By the same device, other people could have arrived at different numbers for the same event because they have different beliefs. Although using the chance wheel takes time, it helps in the process of eliciting numbers. Moreover, it enables us to retest a number given offhand.

It may seem that there is no relation whatsoever between an election and the spin of a pointer on the chance wheel. Of course, there is no *content* relation between the two events. The only relation is the degrees of belief associated with the two events. It is easy to give a number to the event of the pointer stopping but more difficult to give a number to the second event. With the help of one, we get a number for the second event; they are identical numbers when we reach the indifference point.

We will not always be willing to give a precise number. It is possible, for example, that Arthur would have stopped before Step 5, saying, "I can't say more than that the chances are between 25 and 50." Sometimes we don't need a precise number; an interval is good enough. Clarity does not call for a *precise* number. An interval is no less clear than a number. As we didn't always require a narrow, ridiculous definition of the problem in the name of clarity (see Chapter 2), we don't always require it here when specifying degrees of belief.